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CHOICE AMONG STRATEGIES FOR SYSTEM ACQUISITION

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24

ABSTRACT

Improvement in the process of acquiring major weapon systems has been the subject of analyses and policy recommendations for several decades. While system costs have increased as weapon systems have grown more complex, for programs of comparable duration and technical difficulty the extent of cost growth over original estimates has not significantly improved. Furthermore, there is little evidence that procedural changes in recent practices of system acquisition will produce important improvements.

To obtain a better understanding of this evidence, a model capturing the dimensions of and controls over an acquisition program is developed and analyzed. The model includes various dimensions of program performance--not only system performance and program schedule but also development and system cost--as well as acquisition strategies--comprised of combinations of study, test, and demonstration activities; contractor environments and contract types; and sets of decision points for program, technological, or threat reassessment. Choice among strategies can be determined within a budget constraint by the utility of performance dimensions actually achieved to counter threats that actually materialize. The empirical results concentrate on determination of the technological advancement of a system and on investigation of the extent to which program performance flexibility is constrained by the acquisition strategy selected.

CHOICE AMONG STRATEGIES FOR SYSTEM ACQUISITION

Alvin J. Harman*

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Improvement in the process of acquiring major weapon systems has been the subject of analyses and policy recommendations for several decades [see, for example, Klein (1962), Peck and Scherer (1962), Marschak, et al. (1967), Perry, et al. (1971)]. While system costs have increased as weapon systems have grown more complex, for programs of comparable duration and technical difficulty, the extent of cost growth over original estimates has not significantly improved [Harman (1970)].

The objective of this paper is to suggest a new empirical formulation by which the influence on program performance of strategy variations can be measured. Major performance attributes of a program include the technical performance of the end product (e.g., its ability to perform one or several types of missions), the schedule within which it is delivered to operational status, and the price within which the above characteristics are achieved. As a matter of definition, a strategy is the mix of various elements of program structure to achieve the performance outcome (e.g., to achieve maximum technical advancement for a given price and schedule, or minimal cost for a given technical and schedule performance). The *elements* may include studies during the conceptualization of the new system, various test or demonstration activities on either prototype or early production hardware, sets of decision points for technological or threat reassessment and program restructuring, alternative contractor environments and contract

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types, and methods for verification of contract completion.*

While exceedingly complex in practice, conceptually it is straightforward that choice among strategies (involving different combinations of strategy elements) can be determined within a budget constraint by the utility of technical and schedule performance dimensions actually achieved to counter threats that actually materialize. Rather than attempting to deal explicitly with optimality conditions [see Shishko (1971)], empirical evidence of strategy differences can be investigated. One approach would be the study of radically different strategies in use for programs exempt from the usual DoD practices, or in use for similar programs abroad [Alexander (1970), Perry, et al. (1971)]. This approach has the advantage of potentially revealing not only strategies with more predictable outcomes, but also with lower cost outcomes. On the other hand, it is difficult to imagine how such radically different strategies can be implemented within the current DoD institutions. I will therefore focus on methodological considerations and empirical evidence (from DoD programs that employed standard practices) for selection criteria among standard strategy elements.

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*A number of these elements have been the subject of previous theoretical and empirical investigations [see Nelson (1961), Klein, et al. (1971), Scherer (1964, 1966), Cross (1968), Fisher (1968), Hall (1969)].

I. *AN OVERVIEW OF THE WEAPON ACQUISITION PROCESS*

As I have described in greater detail elsewhere, the overall attributes of program performance can be analyzed rather easily provided that certain assumptions are correct [Harman (1970)]. The experience in acquiring major weapon systems can be summarized if the main strategy attributes have not changed radically within the periods of interest. Furthermore, in the process of acquiring new *military* systems, it is reasonably realistic to assume that the system of equations describing the technical, schedule, and price outcomes is block recursive; that the actual price implications of the processes determining technical and schedule performance are not reflected either directly (as a variable in the equations) or implicitly (through correlated disturbances). The case for this assumption rests largely on the subset of military R&D under investigation--rather far along in the R&D process to the point of "system development." While the choice among early R&D projects is likely to reflect price versus technical performance considerations, the choices among reasonably well-defined systems tend to be dominated by technical and schedule considerations. Furthermore, even if attempts have been made during the planning stage to make cost-technical tradeoffs, the changes authorized and inflexibility maintained during the execution of past programs have tended to vitiate these attempts. On the other hand, costs ultimately borne by the procuring service are not completely responsive to severe technical and schedule requirements; other levels and branches of government that have not attempted to control the other performance features do exercise limitations of greater or lesser severity on costs.* As a broad overview of the process, therefore, I have investigated cost consequences of other aspects of program performance, and have employed ordinary least squares.

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*Throughout this paper, I am using "costs" to denote the total program expenditure by the procuring service, and not the total cost to the developer. The latter will be simultaneously determined with technical and schedule performance, while the former may be significantly influenced by that branch of the service as well as other elements of government, resulting in either a profit or loss to the developer.

The model itself deals with the *uncertainty* of cost outcomes; the measure of primary interest has been the cost factor (F), the ratio of actual costs (development and production) of the completed program to the estimate of these costs made at the time of program approval. The hypotheses--that underestimate or growth of actual costs would be increasingly likely for more complex and/or technologically advanced systems, and that the dispersion would tend to increase with these biases--were tested using the equation

$$\log F = a + b\, L \cdot E \qquad (1)$$

in which L is the development program length in months and E represents the intensity of effort per month of development necessary to accomplish the program. This intensity should reflect the performance advancements of the system to be achieved within the schedule provided. The model was used to investigate aircraft and missile acquisitions in the 1950s and 1960s, and to see if any significant difference in the system acquisition process in these decades could be detected.*

Since no direct measurement of E was available, two functions of a subjective measure** of technological advance sought (A) for the system (as a surrogate for the performance advancements) and L were considered. The function selected was simply

$$E = f(A) \qquad (2)$$

That is, E was represented by a monotonic function of the technological advancement subjective measure. Moreover, a stretching of this A dimension provided the best fit.*** A few of the empirical results are reproduced in Table 1 for convenient reference.

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*The measure of L for the 1950s systems was actually the time from earliest estimate (on which the cost factor was based) to development completion (initial operational delivery, IOD). A better measure was found for later analysis, see below.

**For a description of the surveys that produced this measure see [Harman (1970) Section III].

***The A variable ranged from about 5 to 16 on an arbitrary scale of 0 ("off the shelf") to 20 ("basically new and radically different system design"). Four monotonic transforms of A were tested: log A, A, A^2, e^A.

Table 1

SUMMARY RESULTS OF COST FACTOR MODEL[a]

Sample	a	b	R^2	Sample Size
Structure linear in "A" $\log F = a + b\,L \cdot A$				
1950s	.021 (.1)	.00078 (3.4)	.39	21
1960s	.008 (.8)	.00035 (1.5)	.19	12
Combined	-.007 (-.1)	.00076 (4.5)	.39	33
Structure with Stretched "A" Dimension $\log F = a + b\,L \cdot e^A$				
1950s	.268 (2.2)	.15E-08 (4.2)	.48	21
1960s	.180 (4.5)	.33E-08 (4.0)	.62	12
Combined	.240 (3.2)	.15E-08 (5.7)	.51	33

[a]t-statistics are presented in parentheses below coefficient estimates.
Source: Harman (1970) Table 6.

The conclusions of the study were summarized as follows:

> The coefficient estimates in the various structures for the model can be described as characterizations of the system acquisition *process* in each of the two decades. Average values of the development characteristics--[L] ... for development program length and "A" being a measure of technological advance sought--characterize the way in which developments have differed between the decades. The statistical tests discussed above led to the implication that there has been no significant difference in the process between the two decades; one even finds that the process seems to have 'deteriorated' for some types of development programs in the sense that *for a given set of development program characteristics* the cost factor for the 1960s implied by the model would be higher than for the 1950s. Despite this implication for the process, the programs' outcomes--which can be characterized as having resulted from programs in the 1960s that were somewhat shorter and of somewhat lower technological difficulty on the average--have shown a 'typical' 1960s program to have a somewhat lower cost factor than a 'typical' 1950s program. [Harman (1970) pp. 42-43, notation slightly modified, original italics].

There are two features of these results that I will pursue below. First, the "technological advance sought" for a system plays a crucial role in explaining cost uncertainty, and it is particularly the systems with high values for A that have experienced large and essentially unpredictable cost growth.* However, the measure used was obtained subjectively *ex post*. Before a variable like A can be used as a signal for strategy selection--namely, for a high "A" program, find a *different* and hopefully better strategy than has been used in recent experience--a more objective and potentially *ex ante* measure of "technological advance sought" is highly desirable.

The second feature to be considered below relates to the fact that the cost factor model assumes that the strategy for system acquisitions has been essentially the same for all programs considered. While this has been borne out to some extent by the results, it should still be revealing to refine the approach to one in which the impact of variations in different elements of the strategy could be considered.

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*In the results of the 1970 study, this conclusion--a consequence of the selection of e^A as the most appropriate stretching of the A dimension--had to be based largely on the 1950s sample in which 14 of the 21 items in the sample had A's larger than 12 (the 1960s sample had only one of 12). Since that time, the 1960s sample has been expanded and updated. The sample now includes 5 of 19 systems with A's larger than 12 and all results are essentially the same.

II. *TOWARD ALTERNATIVE STRATEGIES*[*]

Quantitative Assessment of Technological Advance

In an effort to see if a measure comparable to the "A" could be obtained, I have investigated technological advancement of fighter aircraft in greater detail. The objective, in effect, is to explore the schedule-technical performance block of the recursive system of equations describing program outcomes. While a detailed investigation of each of these aspects of the acquisition process would be well worth undertaking, for the present I have confined myself to obtaining a summarization of the observed outcomes of this block of the model.

The basic premise for the formulation to follow is that a "most advanced" system can be identified from among all those developed prior to the beginning of each program to be investigated. Such a system can then be used as benchmark for assessing the technological advance of the subsequent development program. The method of selecting this "most advanced" system will be based on the trend-of-technology methodology employed by Alexander and Nelson in their analysis of technological advance in jet engines. The entire procedure is sketched in Fig. 1. The trend methodology involves predicting the time at which a development program will come to fruition based on the performance of the completed system. In effect, the assumption is made that the shape of the tradeoff surface among the performance parameters has remained stable over the period but has *shifted* to higher and higher levels of achievable technology through time.[**] The plotted points in Fig. 1 represent the actual development endings relative to those predicted (calculated) from the regression equation, based on the performance the system has achieved. A point on the 45° line would represent a system completing development just when it would be expected to, based on the trend-of-technology equation. Similarly, points above the line can be interpreted as representing systems with technology ahead of their time and

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[*] The empirical results in this section are quite preliminary due to questions of accuracy and quality of the data that are still being resolved. I believe, however, that the results do yield some insights into the usefulness of the methodologies.

[**] The selection of a benchmark from such a technological tradeoff surface is assumed to yield a system "closest" to the set of performance characteristics of the next system to enter development. This assumption is necessary in making the rates of advancement calculations (see p. 10).

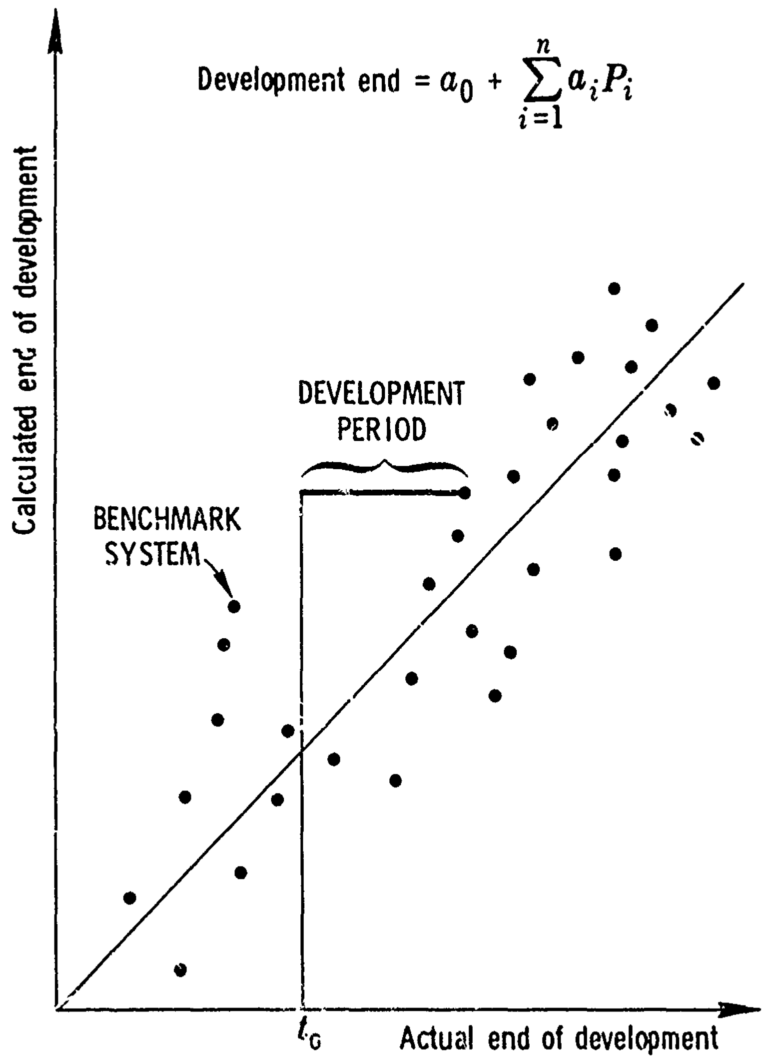

Fig. 1 -- Determining the Benchmark "Most Advanced" System from a Trend-of-Technology Equation

conversely for points below the 45° line. For the current analysis, at any development program beginning t_c, the most recent program (in the case of a tie) with the highest "calculated" end of development (based on the equation using attained performance parameters) will be taken to be the "most advanced" prior system.*

The trend-of-technology equation used for the remainder of the analysis of fighter aircraft is**

$$\underset{}{IOD} = \underset{(.2)}{175} + \underset{(2.5)}{111 \ln s} + \underset{(.09)}{2.4 \ln w} - \underset{(-1.0)}{88 \ln c} - \underset{(-1.3)}{88 \ln wl} + \underset{(1.0)}{150 \ln de} + \underset{(2.4)}{50 \ln cr} \quad (3)$$

$R^2 = .81$

Sample size = 18

where

IOD = months since the beginning of 1940 to the initial operational delivery

s = maximum speed

w = empty weight

c = service ceiling

wl = wing loading (gross weight/wing area)

de = delivery efficiency (gross weight/empty weight)

cr = climb rate

The coefficients that are even marginally significant are plausible in interpretation--"most advanced" (latest) aircraft would have higher speed, lower wing loading (and thus higher maneuverability), greater delivery efficiency, and a greater climb rate. Only the ceiling coefficient seems to be incorrect in sign.

Given this equation and the definition of "state-of-art" in Fig. 1, the two main features necessary to assess the technological advance

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*It would also be interesting to experiment with allowing the benchmark of prior system to overlap somewhat in development program with a new program conducted by the same developer. On the other hand, it might be useful to insist on a minimum length of time between systems before such a system could be considered prior to a current development (i.e., t_0 prior to the actual beginning of development).

**t-statistics are presented in parentheses below coefficient estimates.

for a new development are the performance dimensions sought and the length of the development program--that is, the length of time available to achieve those new performance dimensions. Of course, it is possible that some of the "technology" embodied in this new system will not have been developed specifically for it. With a longer gap between the end of one development program and the beginning of another, the possibility increases that scientific breakthroughs or less dramatic shifts in technology from other systems or programs may be applicable to this new program. I deal with this other means of "advancing technology" shortly.

The technological advance required in a particular program, then, is a function of the growth of each of the performance dimensions of the new system from the performance dimensions already available in the "most advanced" system in the force. If $P_i(1)$ is the ith performance attribute characteristic of the "most advanced" recent development, the $P_i(2)$ is the corresponding performance dimension for the new development program, then the rate of growth in that performance dimension in the course of development is given by

$$r_i = e^{\left[\frac{\log P_i(2) - \log P_i(1)}{(L/12)}\right]} - 1 \qquad (4)$$

That is, r_i is the annual compound rate of growth* of the ith performance dimension necessary to achieve $P_i(2)$ during the development program of length, (L/12) years.

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*The choice of *compound* growth is based on the premise that some of the early results of a development program are useful in the formulation of later development efforts. The extent of compounding is somewhat arbitrary--running the gamut from simple growth rates (i.e., no compounding, which can be thought of as all components of the project developed in parallel and assembled at the very end, so no solution early in the development is helpful in a later problem) through annual compound growth rates, monthly compound growth rates, to instantaneous compounding (i.e., every "idea" or thought by anyone in the development effort may be helpful at a later point in the development). The annual compounding is an intermediate choice between these extremes.

Even after using all of the major performance dimensions for a particular type of weapon system, there are several aspects of technological advance that are certainly not captured by these rates of growth. As mentioned earlier, one important aspect is the possible availability of research or scientific advancement not associated with the development of a particular weapon system. The length of time between the "most advanced" development program completion and the beginning of the current one can be identified by the slack variable, SL.* One might also want to capture major technological barriers that are crossed in the course of particular development programs. For example, to differentiate aircraft designed to operate at supersonic speeds, the variable rate of growth of maximum speed could be dichotomized into a subsonic category and a supersonic category. For the current analysis only the r_i's and the SL variable are included as the set of variables describing technological advance of a program.

It would be quite plausible to use this entire set of variables as the characterization for the observed technological advance outcomes of the technical and schedule performance block of the model. However, it seems equally reasonable to postulate underlying characteristics of the development process that produce this set of outcomes. For example, progress in materials, aerodynamics, and engines largely determines the progress in most observable measures of technical performance. To take this last step, of parsimonious description of such underlying dimensions of the technological advance, I have employed factor analysis.**

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*It might be valuable to distinguish between this slack variable between development of different fighters and a second slack variable identifying the length of time between development programs by a particular developer. This might capture some of the momentum aspect of maintaining a design team that has recently learned from past design effort and could apply its recent experience to design of subsequent systems.

**The MINRES method of initial solution (a least squares solution for the factor loadings and communalities simultaneously) and DIRECT OBLIMIN (an oblique) rotation have been used. For a description of the similarity between simultaneous equation estimation and factor analysis, see [A. S. Goldberger (1971)].

Of course, the degree of success in achieving such a description of *underlying* dimensions depends on the corrections of the benchmark selection as well as the appropriateness of the linear factor analysis model.

The rotated factor loadings are presented in Table 2.

Table 2

FACTOR ANALYSIS RESULTS

Variables	Z_1	Z_2	Communality
r_s	.718	.040	.520
r_w	-.591	-.389	.523
r_c	.079	.912	.844
r_{wl}	.955	-.309	.978
r_{de}	.386	-.497	.378
r_{cr}	.669	.567	.805
SL	.595	-.056	.354
Variance captured by factors	2.76	1.68	
Correlation between factors	.05		

The primary attributes that are positively associated with the first factor (Z_1) are increases in speed, wing loading, and, to a lesser extent, the delivery efficiency and climb rate. The slack variable is also described essentially entirely in terms of the first factor. That is, phenomena occurring outside the development program are correlated positively with this "underlying dimension." Overall, for the sake of having a label, I might call this first factor "speed (with ease)." The main idea behind this name is that both the speed and wing-loading dimension are quite strongly captured by the first factor. More important to the "(with ease)" part of the epithet, this factor implies greater growth in the speed dimension if the slack period between programs is large, so that advances not undertaken (and not paid for) in the current development program could be embodied in the current aircraft. "Speed (with ease)" doesn't adequately capture the extent to which the first factor described the climb rate; such a name is simply an abbreviation for the set of technical performance improvements that are associated with the factor, as detailed in Table 2.

Clearly, both the ceiling and the climb rate advances are very strongly associated with the second factor. For this factor, also, the positively valued performance attributes are attained in part by a tradeoff between weight and these dimensions. The speed and slack variables are essentially not influenced by the second factor. As a label for the second factor, I would use a "ceiling and climb" characterization. These two factors are essentially uncorrelated, although it would be quite plausible that the two factors described above be positively correlated, since most influences captured in a positive manner by either factor are considered desirable for advancement in fighter aircraft. This lack of correlation suggests that program objectives in the first dimension can be sought independently of objectives in the second.

By obtaining factor measurements, I am in a position to test the meaningfulness of the subjective technological advance measure, A, in the cost factor model. Specifically, A can be handled as a variable measured with noise, and the Z_i's can be used as instrumental variables in an errors-in-variables formulation to improve the estimation of parameters of the cost factor model.

Since there were only six fighters in the previous analysis (all from the 1950s sample) for which Z_i's have been obtained, these results are more suggestive than conclusive.* In Table 3 the estimates of the cost factor model are presented for three cases: with the original subjective measure of A, with an estimated A from a linear regression on the Z_i's [represented as A(Z)], and with the latter measure of technological advance and an improved measure of program length for each system that was used in the calculation of the rates of improvement in (4).** The results, both for the six fighters alone and for the

*The "A" measure for these six does have a broad range--from 8.5 to 15.2 (the entire 1950s sample ranges from 7.0 to 16.0).

**To distinguish these two measures of program length, the one used in the previous cost factor analysis is called "LA;" the improved measure is "LZ."

Table 3

COST FACTOR MODEL USING Z_i's TO IMPROVE MEASUREMENT OF A

Equation	Structure Linear in "A" $\log F = a + b\,L \cdot A$			Structure with Stretch "A" Dimension $\log F = a + b\,L \cdot e^A$		
	a	b	R^2	a	b	R^2
Six fighter subsample						
LA · f(A)	-.174	.0010	.45	.109	.35E-08	.57
	(-.5)	(1.8)		(.5)	(2.3)	
LA · f(A(Z))	-.167	.0010	.46	.131	.22E-08	.59
	(.5)	(1.9)		(.6)	(2.4)	
LZ · f(A(Z))	-.285	.0010	.64	.130	.18E-08	.59
	(-1.0)	(2.7)		(.6)	(2.4)	
1950s aircraft and missiles sample						
LA · f(A)	.021	.0008	.39	.268	.15E-08	.48
	(.1)	(3.5)		(2.2)	(4.2)	
LA · f(A(Z))	.020	.0008	.39	.254	.15E-08	.52
	(.1)	(3.5)		(2.2)	(4.5)	
LZ · f(A(Z))	-.013	.0008	.42	.250	.14E-08	.53
	(-.1)	(3.7)		(2.2)	(4.6)	

Note: t-statistics are presented in parentheses. The equations in the first line of the "1950s aircraft and missiles sample" are reproduced from Table 1.

entire sample with "corrected" A measures in these six cases, show that the estimates for the parameters remain essentially unchanged but the significance of the estimate of the "b" parameter increases. The one case in which the coefficients are quite different is that of the "stretched" subjective A measure with the six-fighter subsample. In this case the "b" coefficient is .0000000035, double the value estimated in other analyses of the 1950s. However, when the improved measures are used--more accurate measures of program length and estimates of A from the Z_i's--the coefficient becomes nearly the same as those estimated for the larger sample; that is, .0000000018. In short, improvement both in measurement of technological advancement and program length lead to increased confidence in the measurement o, parameters of the cost factor model and therefore in its use as a signaling device for the need to devise alternative strategies.*

Evaluation of Strategy Elements

To deal with some of the detailed elements of acquisition strategies, it will be necessary to abandon the cost factor representation of program performance. The change I will introduce involves the premise that the *functional relationship* explaining cost outcomes based on schedule and technical considerations changes between the early planning for a new system and the time after initiation of the development program.

Specifically, with efficient planning, schedule stretchouts before development commences can be traded off for lower total program costs indefinitely. I have selected a rectangular hyperbola as a reasonable specification for such a relationship; see Fig. 2(a). Basically, the type of "friction" of schedule stretchouts arguments used to justify the U-shaped cost curve do not apply if a development program has not proceeded to the point at which a labor force might be forced to remain idle or management coordination of a long program becomes inefficient. At this early stage, it is even feasible to postpone initiating the development; present discounted costs decline as program initiation is postponed. Once a program is initiated according to a particular strategy (e.g., planned time for development, incentives for meeting certain milestones, etc.), unforeseen technological difficulties or changes in the system sought (due, for example, to a changed perception of threats) can lead to increased system cost even if handled efficiently. I depict this implementation *strategy*

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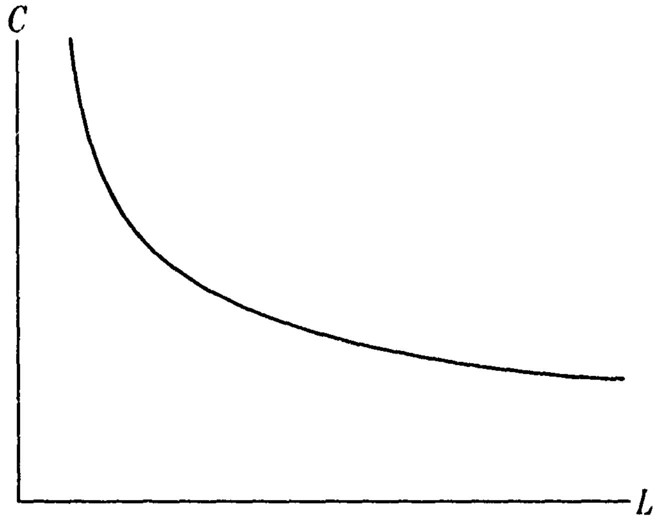
*I have previously pointed out that the e^A stretching of the A dimension may mean that small technological advances have little effect on the unpredictability of costs *or* that the survey measure used may not be very sensitive to the lower levels of technological advance, but can only distinguish these from the very highest [Harman (1971) p. 24].

These results--while extremely limited because of the sample size involved--provide the first evidence that the latter interpretation may be correct. That is, with this "quantitative" measure of technological advance (and better measure of program length), the linear (more gradual) influence in the cost factor model is now marginally "preferred."

a) CONCEPT FORMULATION TRADE-OFFS



b) STRATEGY IMPLEMENTATION

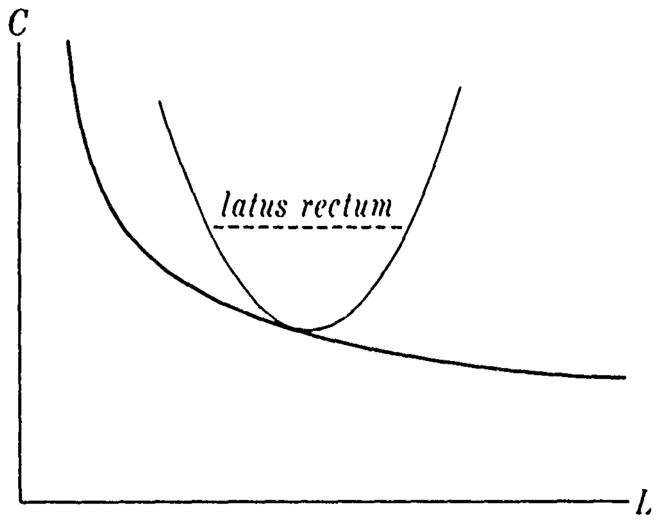


Fig. 2 -- Cost-Schedule Choice for a Given
Technological Advance

for the program as a parabola within the envelope of possible cost-schedule choices; see Fig. 2(b). A program that can be changed relatively cheaply in response to modest alteration of objectives is one characterized by a relatively broad parabola. Thus, the *latus rectum** of the parabola can be used as one measure of the cost flexibility of particular strategies.

The formulation for the conceptualization phase of a new program, then, is

$$(C - C_{min})\ (L - L_{min}) = k \tag{5}$$

in which C is, as before, the total of development and production costs of the new system, and L is development program length.** Since the model is designed mainly to deal with outcomes of R&D, it would be desirable to consider separately the technology-advancing and cost-reducing aspects of the program. Unfortunately, such a refined breakdown is simply not possible with the available data. Therefore, C_{min} is used to allow crudely for the production costs if no R&D were necessary. The height above this level is dependent on the ambitiousness of the R&D phase; it can be approximated by a measure of technological advance sought, which could influence both L_{min} and k. To simplify the formulation, I assume that all the influence of technological advance can be captured within k; that is, that if R&D funds approach an infinite amount, the R&D time can approach zero. Restating equation (5), the model during concept formulation becomes

$$C = C_{min} + \frac{kf(A)}{L} \tag{6}$$

I should really stop here for a number of reasons. First, the information I have on the programs in the 1960s sample is extremely limited. Even if I could estimate this hyperbola (a question I will take up momentarily), I have only extremely crude information on the

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*The *latus rectum* is the distance across a parabola at the height of the focus. This is indicated by the dashed line in Fig. 2(b).

**This rectangular hyperbola can be translated into the first quadrant by allowing the horizontal asymptote (i.e., C_{min}) and the vertical asymptote (i.e., L_{min}) to be positive.

elements of strategy used for each program. For example, information on the total number of contractors and contracts is available, but the timing of the individual decisions to initiate one or several contracts--needed for an assessment of the contractor environment (e.g., sole source or not) and buyer information (e.g., was test information available?)--is not yet assembled. Similarly, contract types are known but only at the crude level of the designation: fixed-price-incentive, cost-plus-incentive-fee, firm-fixed-price, and cost-plus-fixed-fee. No sharing rates or details of the features upon which the incentives are based has been assembled, nor do I know if contract "ceilings" have been exceeded (at which point the contract, however designated, becomes either a firm-price or a cost-plus type). I have some information on the timing of the test phase, but not on the *planned* timing to be related to planned decision points for the program--most relevant to the question of "prototype" versus "concurrent" development strategies [see also, Klein, et al. (1971)].

The other major stumbling block to further analysis is the problem of estimating the hyperbola (6). The case that this cost equation, based on *planning* considerations within the DoD, is part of a block recursive system would appear to be rather weak. Of course, that only involves the question of the best method of estimation, provided that the equation remains identified. But the problem of determining the envelope within which all feasible program outcomes must occur demands much more complete program planning information and assessment of technical difficulty than is now available.

Having said this, I will briefly report some first indications of results, as a solicitation of your comments and suggestions. I have used ordinary least squares to estimate equation (6), with the term $Q \cdot Wt$ (quantity, weighted by the empty weight of the item involved as a proxy for production resources involved) to capture C_{min}, and with various transformations of the subjective A measure of technological advance sought, for the 1960s aircraft and missiles sample. The equation with $f(A) = A^2$ produced the best fit (although no transformation of A yielded radically different explanatory power):*

$$C = -.64 + \underset{(-.3)}{} \underset{(11.5)}{.78} \times 10^{-6}\, Q \cdot Wt_{ac} + \underset{(5.9)}{.71} \times 10^{-6}\, Q \cdot Wt_m + \underset{(1.2)}{.79}\, A^2/L \quad (7)$$

$$R^2 = .94$$

A strategy parabola was then calculated for each system based on three pieces of information: the *planned* cost and program length [used in estimating equation (6)], the slope of the hyperbola [equation (7)] to which the parabola is to be tangent at that program length, and the *actual* cost and program length of the completed system.

Let me conclude by indicating the kind of implications that may be feasible with this formulation of strategy influences. I have plotted the *latus recta* of these parabolas against one of the strategy elements--the proportion of all major contracts for a program that involved government cost-sharing in the development phase (see Fig. 3). This choice of contract types distinguishes two things. Within the development phase it distinguishes contracts for which government agreements on the "target" and "allowable" costs are important. Since target cost is less readily determinable for development activities, one would expect the incentive to achieve costs below target to be most easily perverted by the incentive to raise the target for these contracts [see also, Fisher (1968)]. The second aspect of this proportion is that it crudely captures the decisions and relative need for development activities as distinguished from production activities. That is, a proportion of unity implies that a commitment was made for the entire program at the beginning of development ("Total Package Procurement"), whereas a low proportion indicates either a reliance on firm-fixed price development contracts or relatively little need for development activities.

Since some programs had very little change between planned and actual development program length (and since the *latus rectum* will

*In the equation, C is measured as 10^8\$ and separate coefficients have been obtained for "C_{min}" for aircraft and for missiles within the sample. The t-statistics are presented in parentheses below the coefficient estimates.

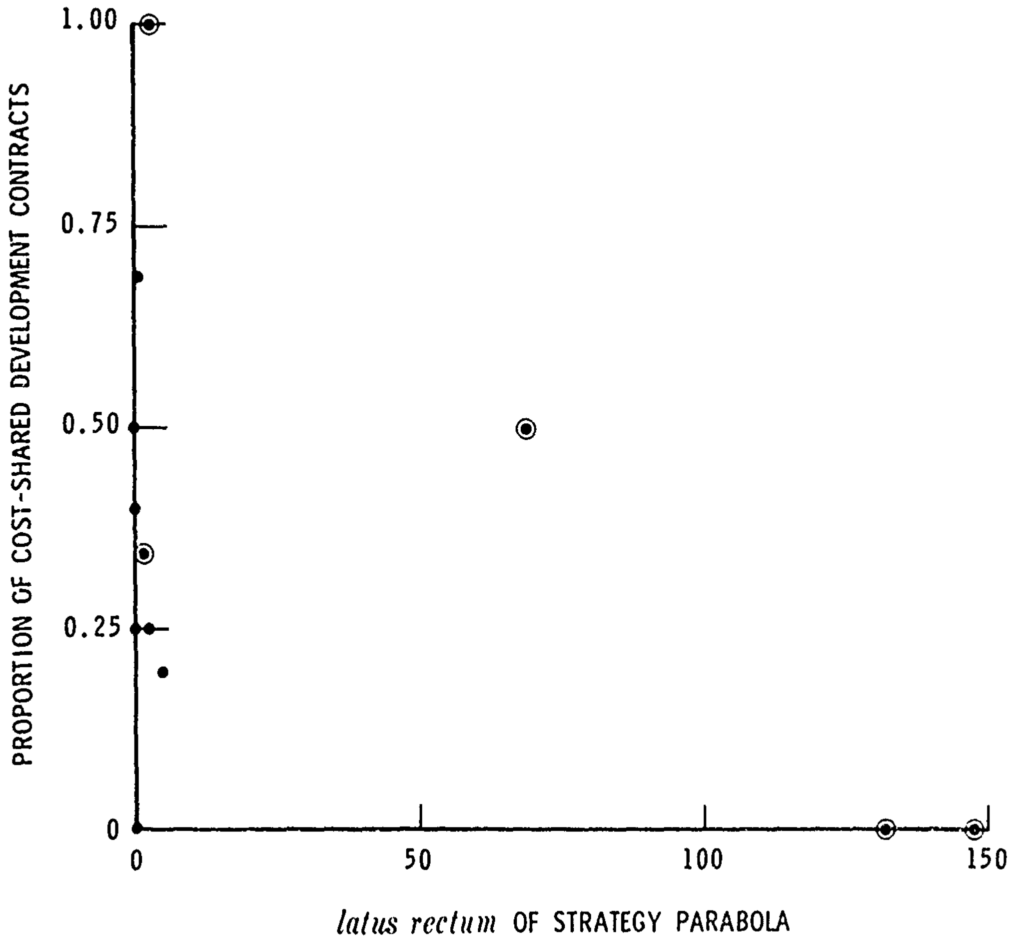

Fig. 3 -- Extent of Cost Flexibility with Cost-Shared Development "Strategy"

approach zero as the difference between planned and actual program lengths goes to zero), the plot points for programs with schedules deviating from planned by more than 4 months are circled. For these, there is no correlation between differences of planned from actual program length and size of the *latus rectum*, and there does appear to be a pronounced tendency for more cost-shared features to constrain the cost flexibility of (i.e., reduce the *latus rectum* of the strategy parabola representing) the program.

In summary, the objective of this exercise has been to suggest a model formulation that may be useful in identifying low-cost acquisition strategies based on strategy elements that have been used in recent experience. Of course, more detailed data and many other elements of the strategies must be considered simultaneously before any such inferences can be drawn with confidence.

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